DTU Library

Cascadability of Silicon Microring Resonators for40-Gbit/s OOK and DPSK Optical Signals

Ozolins, Oskars; An, Yi; Lali-Dastjerdi, Zohreh; Ding, Yunhong; Bobrovs, V.; Ivanovs, G.; Peucheret, Christophe

Published in:
ACP Technical Digest

Publication date:
2012

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Ozolins, O., An, Y., Lali-Dastjerdi, Z., Ding, Y., Bobrovs, V., Ivanovs, G., & Peucheret, C. (2012). Cascadability of Silicon Microring Resonators for40-Gbit/s OOK and DPSK Optical Signals. In *ACP Technical Digest* (pp. AS1G.1). Optical Society of America.

Cascadability of Silicon Microring Resonators for 40-Gbit/s OOK and DPSK Optical Signals

O. Ozolins[(1,2)], Y. An[(2)], Z. Lali-Dastjerdi[(2)], Y. Ding[(2)], V. Bobrovs[(1)], G. Ivanovs[(1)] and C. Peucheret[(2)]
(1) Telecommunications Institute, Riga Technical University, LV-1048, Riga, Latvia
(2) Department of Photonics Engineering, Technical University of Denmark, 2800 Kgs. Lyngby, Denmark
Author e-mail address: oskars.ozolins@rtu.lv, cpeu@fotonik.dtu.dk

Abstract: The cascadability of a single silicon micro-ring resonator for CSRZ-OOK and CSRZ-DPSK signals is experimentally demonstrated at 40 Gbit/s for the first time. Error-free performance is obtained for both modulation formats after 5 cascaded resonators.
OCIS codes: (060.2330) Fiber optics communications; (230.5750) Resonators.

1. Introduction

Silicon micro-ring resonators (MRRs) are versatile devices with promising applications as optical filters or wavelength selective switches [1]. One straightforward use of MRRs is as optical add-drop multiplexers in wavelength division multiplexing (WDM) systems. Furthermore, thanks to their compactness, integrability, and compatibility with standard microelectronic fabrication processes, they are essential building blocks for future scalable optical interconnects architectures [2], which have recently been the object of increased research interest. Even though they are designed for high-speed networks or interconnect applications in mind, very few studies have so far considered the impact of MRR filtering on high-speed modulated signals. The system penalty induced by one single or double ring resonator structure on 10-Gbit/s non-return-to-zero (NRZ) on–off keying (OOK) signals has been first investigated in [3] and [4]. Very recently, switching of 10-Gbit/s differential phase-shift keying (DPSK) signals through a second order silicon micro-ring switch has been demonstrated [5]. Higher order MRRs are used in this context since their wider and flatter passbands prevent the occurrence of phase-to-intensity modulation conversion [5]. The bit-error-ratio (BER) performance of coupled ring resonators has also been given recent consideration [6] for NRZ OOK signals at 10 Gbit/s. However, for MRR-based scalable high-speed interconnect architectures or WDM add-drop nodes to constitute a practical solution, the cascadability of the MRRs should be ensured for high bit rate signals, which has not been demonstrated so far.

In this paper, the cascadability of silicon MRRs used as bandpass filters to their drop port is experimentally investigated for carrier-suppressed return-to-zero (CSRZ) OOK and CSRZ-DPSK signals at 40 Gbit/s. A re-circulating loop platform is used to assess the impact of the MRR transfer function on high-speed modulated signals. Error-free performance is demonstrated for both CSRZ-OOK and CSRZ-DPSK after 5 cascaded silicon MRRs with free spectral range (FSR) of 1235 GHz and Q factor of 2182. A higher tolerance to bandwidth reduction is obtained for CSRZ-OOK compared to CSRZ-DPSK due to the partial demodulation of the latter format induced by cascaded bandwidth narrowing.

2. Device fabrication and characterization

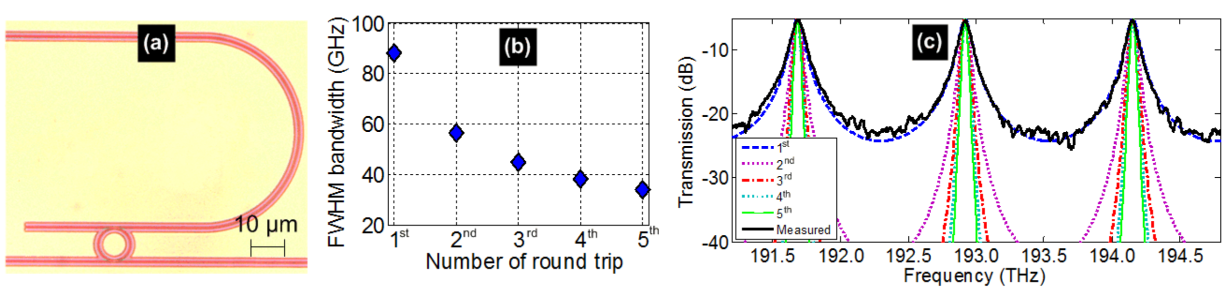

Fig. 1. MRR used in the experiment: (a) top view; (b) calculated FWHM bandwidth reduction due to cascading; (c) measured transfer function of the drop port, its fit and cascaded fitted transfer functions.

The silicon MRR used in the experiment is represented in Fig. 1(a). It was fabricated on a silicon-on-insulator (SOI) wafer with top silicon thickness of 250 nm and buried silicon dioxide of 3 μm. Details of the fabrication process can be found in [7]. The radius of the MRR is 9 μm, with 80-nm coupling gap and 435-nm waveguide width. The input and output waveguides were inversely tapered to 45 nm and covered by polymer. This forms a nano-coupler, which results in ultra-low coupling loss to and from tapered fibres [7]. Fig. 1(c) shows the measured transfer function at the drop port of the MRR. The measured FSR is 1235 GHz and the Q factor is 2192, corresponding to a full-width at half-maximum (FWHM) bandwidth of 88 GHz. The total insertion loss of the device is about 5 dB and the extinction ratio (ER) of the drop transmission is 20 dB.

3. Experimental setup and results

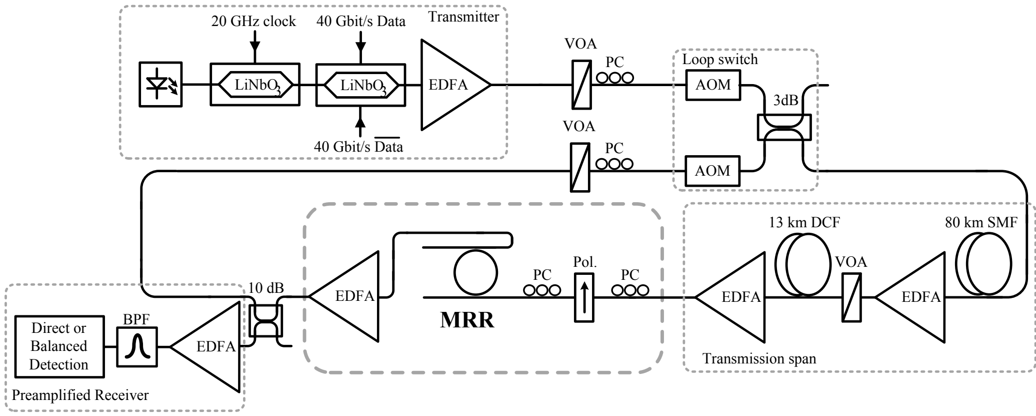

Fig. 2. Recirculating loop setup for MRRs cascadability evaluation.

The experimental recirculating loop setup for investigating the cascadability of a single MRR used as drop filter is illustrated in Fig. 2. The optical transmitter consisted of two $LiNbO_3$ Mach-Zehnder modulators (MZMs) generating 40-Gbit/s CSRZ-OOK or CSRZ-DPSK signals. The first MZM, driven by a half clock, was used as pulse carver while the second one was driven by a 40-Gbit/s pseudo random binary sequence (PRBS) with a pattern length of 2^{31}-1. The optical signal was then boosted by an erbium doped fiber amplifier (EDFA) before being input to the loop. The loop switch consists of two acousto-optic modulators (AOMs). A dispersion compensated span consisting of 80 km standard single mode fiber (SSMF) and 13 km dispersion compensating fiber (DCF) was used to store the data in the loop and enable the recirculations. After the transmission span, the optical signal was coupled into the MRR via a tapered fiber and collected again at the drop port by another tapered fiber. An EDFA was used for compensating the insertion and coupling loss of the resonator and loop switch. Data was continuously sent, via a 90/10% coupler, to the receiver. Gating of the BER test-set and the oscilloscope enabled the characterization of the signal after the last round-trip in the loop. The signal was detected in a preamplified receiver, comprising a 45-GHz photodiode for OOK and a 1-bit fiber delay interferometer followed by a balanced detector, also with 45-GHz bandwidth, for DPSK. Since the MRR is polarization sensitive, it was ensured the signal at its input was properly polarized for each round trip. This was achieved thanks to a polarizer (Pol.) at its input, and intra- and extra-loop polarization controllers (PCs) enabling to find a stable principal state of polarization for the loop.

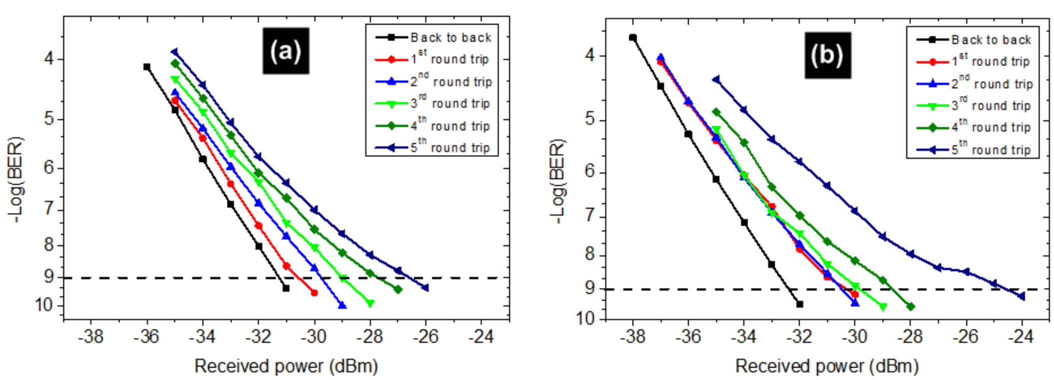

Fig. 3. BER as a function of received power for different number of round trips in the loop and for (a) CSRZ-OOK and (b) CSRZ-DPSK modulation.

Fig. 3 shows the results of BER measurements for the 40-Gbit/s CSRZ-OOK and CSRZ-DPSK signals transmitted through different numbers of round trips in the loop. The penalty when increasing the number of circulations is induced by bandwidth narrowing, as represented in Fig. 1(b), resulting in waveform degradation and intersymbol interference. The CSRZ-DPSK format can be seen to exhibit larger penalty than CSRZ-OOK. However, dispersion management and noise accumulation are critical at 40 Gbit/s and some of the measured penalty is actually attributed to the necessary transmission span in the loop.

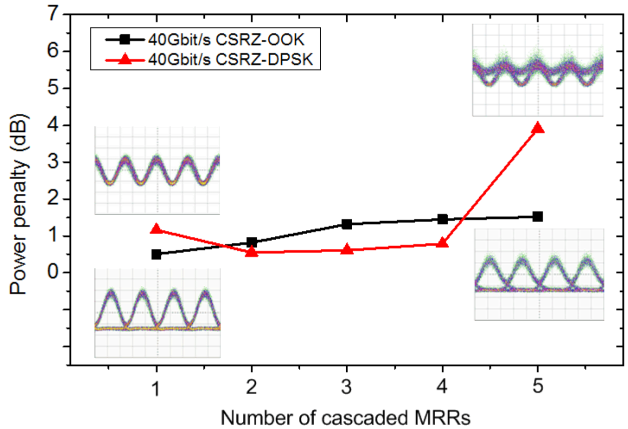

Fig. 4. Power penalty (at BER= 10^{-9}) induced by cascading a single MRR versus number of cascades for CSRZ-OOK and CSRZ-DPSK signals. Insets: eye diagrams after the 1st and 5th round trips.

In order to isolate the impact of the MRR on the transmission performance from that of the cascaded transmission spans and loop artifacts, the recirculating loop measurement was repeated with a (broad) 3-nm FWHM thin film filter (TFF) replacing the MRR. The bandwidth of the TFF was chosen to be wide enough to ensure the signal was not affected by any filtering effect even after 5 round trips. A variable optical attenuator (VOA) was inserted in the loop to emulate the insertion loss of the MRR in order to ensure a fair comparison with respect to noise accumulation. The isolated impact of the MRR is compared for the two modulation formats in Fig. 4, where the transmission penalties obtained from the measurements with the wide TFF have been subtracted from the power penalties measured with the MRR in the loop. A power penalty around 1 dB is measured after one single MRR due to its relatively wide 88-GHz FWHM bandwidth. Similar levels of power penalty are measured for both formats up to 4 cascaded MRRs. After 5 cascaded MRRs, the effective bandwidth of the cascade is reduced to 34 GHz, at which value some DPSK signal demodulation [8] occurs, as can be seen in the corresponding eye diagram in the inset of Fig. 4. This results in an increased penalty for CSRZ-DPSK compared to CSRZ-OOK.

4. Conclusions

We have experimentally demonstrated the cascadability of a single silicon MRR and its impact on the performance of 40-Gbit/s CSRZ-OOK and CSRZ-DPSK optical signals for the first time. Error-free performance with moderate penalty was measured for both formats after up to 5 cascaded MRRs. The CSRZ-OOK format exhibits a better tolerance to bandwidth narrowing than CSRZ-DPSK, due to the partial DPSK demodulation experienced by the latter format when the effective bandwidth of the MRR cascade is reduced.

Acknowledgements

This work was supported by the European Social Fund within the project "Support for the implementation of doctoral studies at the Riga Technical University". Support from the 7th framework program of the European Commission through the DAPHNE (ref. 233709) project and the EURO-FOS (ref. 224402) network of excellence is also acknowledged.

[1] W. Bogaerts et al., "Silicon microring resonators," Laser Photonics Rev. **6**, 47-73 (2012).
[2] D. Siracusa et al., "Hybrid architecture for optical interconnection based on micro ring resonators," Proc. GLOBECOM (2011).
[3] A. Melloni et al., "Experimental evaluation of ring resonator filters impact on the bit error rate in non-return to zero transmission systems," Opt. Commun. **234**, 211-216 (2004).
[4] B. G. Lee at al., "Transmission of high-data-rate optical signals through a micrometer-scale silicon ring resonator," Opt. Lett. **31**, 2701-2703 (2006).
[5] L. Xu et al., "DPSK transmission through silicon microring switch for photonic interconnection networks," IEEE Photon. Technol. Lett. **23**, 1103-1105 (2011).
[6] C. Ferrari et al., "Penalty-free transmission in a silicon coupled resonator optical waveguide over the full C-band," Opt. Lett. **36**, 3948-3950 (2011).
[7] Y. Ding et al., "Generation of a 640 Gbit/s NRZ OTDM signal using a silicon microring resonator," Opt. Express **19**, 6471-6477 (2011).
[8] Y. Ding et al., "Multi-channel 40 Gbit/s NRZ-DPSK demodulation using a single silicon microring resonator," J. Lightwave Technol. **29**, 677-684 (2011).